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Project TED NAM AE-42222, Part 2
DETECTABILITY OF NAVAL AIRCRAFT BY VISUAL MEANS,
MEASURES TO INCREASE OR REDUCE; DEVELOPMENT OF

Aircraft Detectability and Visibility;
I. Visual Fields for Fluorescent and Ordinary Paints

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AIRCRAFT DETECTABILITY AND VISIBILITY:

I. Visual Fields for Fluorescent and Ordinary Paints

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ABSTRACT

This is the first of a series of studies by Applied Psychological Services in collaboration with the Air Crew Equipment Laboratory in which the effective stimulus properties of certain fluorescent pigments (red-orange, yellow orange, and blue) are compared among themselves and with those of "matching" ordinary pigments and white. Through visual perimetric methods, two points were measured on each of eight meridians: (1) that point at which the stimulus was first seen, usually as a gray object, as it was brought in from the periphery ("Outside Limits" measurement), and (2) that point at which the true color of the test object could be identified ("Inside Limits" measurement). For the yellow orange fluorescent and its ordinary color counterpart and for white, only the first of these measurements was made. With respect to the Inside Limits zones, the largest visual field was found for fluorescent blue. Ordinary blue, fluorescent red-orange, and ordinary red-orange followed respectively. With respect to the Outside Limits threshold, the fluorescent stimuli as a whole yielded larger average fields than did their ordinary color counterparts.

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I. INTRODUCTION AND PURPOSE

The increase in frequency of mid-air collisions has focused increased attention upon the problem of maximizing aircraft detectability and visibility. At the present time, appropriate collision avoidance by the pilot encompasses a series of behaviors initiated on the basis of information received through the visual sense modality. Even if supplementary intruder warning devices become a part of the display information presented to the pilot, visual survey of the sky will, in all probability, serve to check on the information obtained from such devices and as a check on the appropriateness of any evasive action taken.

Thus, paint schemes and exterior aircraft coatings which will increase aircraft visibility and/or detectability are potentially of real significance in the solution of the collision avoidance problem.

Of course, it is realized that paint schemes which allow for increased aircraft detectability and visibility will not, per se, solve the mid-air collision problem. The solution of this problem requires systematic consideration of many factors, including at least: (1) the development of a manageable air traffic control system with skilled and trained air controlmen, (2) alert pilots who continuously scan for intruding aircraft and who quickly take the appropriate evasive action, (3) a "milieu" which emphasizes safety, (4) consistent administration of air traffic violations, (5) more highly developed techniques for communication, (6) clearly defined rules and standards for collision avoidance maneuvers, (7) comprehensive training of all pilots in these maneuvers, and so forth.

Nevertheless, it is believed that some advantage might accrue solely from the use of paint schemes which allow in-flight detectability and visibility at greater distances.

The study reported here is the first of a series focusing upon the selection of an optimum paint scheme for these purposes. While high visibility paints have been previously investigated (Halsey, Curtis, and Farnsworth, 1955), to our knowledge no studies have been reported which have systematically focused on fluorescent paints to determine what, if anything, they add to aircraft detectability and visibility and how they compare with ordinary paints in these respects. Additionally, most previous studies have emphasized color alone. In the present Applied Psychological Services - Air Crew Equipment Laboratory studies, stimulus properties such as pattern, area, and brightness contrast are under investigation. Once a body of knowledge has been accumulated as the result of systematic psychological investigation in the laboratory, the results will be applied towards the derivation of aircraft paint schemes which optimize aircraft detectability and visibility. The schemes so derived will then be cross-validated under actual and simulated flight conditions.

Visual Perimetry

If a person monocularly fixates a point in front of him and if a colored test object is moved from the fixation point outward, a limit is reached at which he no longer sees the disk as colored, but rather as gray. Similarly, if the colored disk is moved slowly inward from the periphery, the subject first sees a gray object and then reports the color after the disk has been moved further inward.

Under constant conditions the general results obtained in measuring peripheral color vision are: yellow and blue yield the greatest visual fields; red and green yield smaller fields than yellow and blue; all colors are seen in the central field of vision.

It is known (Boring, 1942, pp. 174-176) that any color zone will vary in size in accordance with the "effectiveness" of the stimulus used. Figure 1 presents the color zone limits as a function of the energy (watts) of the stimulus. In Figure 1 a horizontal line drawn at any level shows the limits of the color zones at that level.

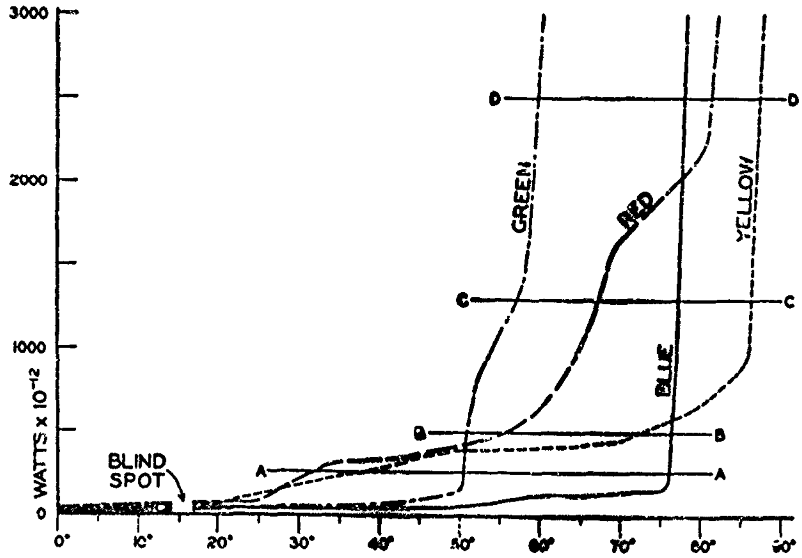

Figure 1 Color zone size as a function of energy

(Data of Ferree and Rand, Psychol. Rev., 1919, 26, 16-41. Reproduced from Boring, 1942.)

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Fluorescent paints or pigments, like ordinary pigments, reflect portions of the spectrum of incident light and absorb other portions. However, with fluorescent paint, "...most of the absorbed portion of light is not dissipated as heat...but, instead, is transformed into emitted light of the same hue as that being reflected by the pigments. Reflected color is thus reinforced with emitted color, producing hues which appear extraordinarily bright to the eye of an observer" (Ref. 4, p. 1).

Thus, if we assume, on the basis of the apparent brightness of fluorescent paints, that these paints reflect more energy, it can then be expected that fluorescent paints will yield greater zonal limits than corresponding colors produced with ordinary pigments.

It seems logical to assume that the paint which yields the greater visual field might possess certain (at least theoretical) advantages for increasing aircraft detectability and visibility. As the aircraft, appropriately painted, moves out of the central field of fixation, color fidelity and object awareness would be retained over a greater time period. As the aircraft moves into the visual field, its presence would intrude on the awareness of the pilot earlier.

Purpose of the Present Experiment

While the visual fields for ordinary colors have been derived, no systematic comparison of these fields has been made with the fields produced by fluorescent pigments. The specific purposes of the present experiment were: (1) to compare the extent of the color zones produced by ordinary and fluorescent paints, and (2) to derive the relative visual fields produced by various fluorescent paint pigments.

II. METHOD AND PROCEDURE

Three fluorescent colors were selected for study: red-orange, yellow-orange, and blue. The chips from which these stimuli were cut were prepared and supplied by a manufacturer of fluorescent paint.

Ordinary paint stimuli were used in order to establish a reference base against which the fluorescent stimuli could be compared.

Selection of Comparison (Ordinary) Colors

The first consideration was that of determining ordinary paint colors which could serve as adequate, "standard" comparison stimuli for the selected fluorescent paints. The approach taken was essentially phenomenological. It was based on the assumption that those comparison stimuli would be most adequate which most closely approximated the chromatic color of the fluorescents*.

A large number of commercially available paint chip and colored paper samples were obtained. Those were selected which bore some similarity in color** to the fluorescent standards and were used to form

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* These comparison stimuli should not be looked upon as controls in the usual sense. Although there is some evidence (Halsey et al., 1955) that saturation is a more effective factor than brightness in contributing to high detectability, it would be presumptuous of the data at this point (and not in line with the purposes of the present research) to attempt to control for hue and brightness (or their spectro photometric correlates) and allow saturation (or its correlate) alone to vary. What is important is that the colors chosen as comparison stimuli approximate the fluorescent standards in all three perceived attributes ("chromatic color") enough that, except for those effects resulting from the property of "fluorescence" (which would manifest itself as an increase in both brightness and saturation), the standard and the match are as closely equivalent as possible. The term "match" as used here is meant to be equivalent only to the comparison colors as defined.

** The single term "color" will be used throughout the rest of this report in place of the more technically acceptable term "chromatic color." The meaning, of course, remains the same.

a series of stimuli from which observers could select those colors which they considered to best match the fluorescents. Four observers first independently matched each of the fluorescents with one of the ordinary colors in the series under the illumination of a 60-watt Mazda daylight bulb situated three feet above the stimuli, and again under much more intense illumination provided by four 375-watt reflector flood lamps situated approximately five feet above and perpendicular to the stimuli. Both the fluorescent and comparison stimuli were pasted on gray cardboard backgrounds possessing a reflectance of approximately 40 per cent. Three of the four observers agreed in the case of the best match for fluorescent red-orange and fluorescent yellow-orange; all four agreed in the case of the match for fluorescent blue. Since the selected match for fluorescent red-orange was chosen from among the colored paper samples rather than from the paint chip samples, a paint was then mixed which matched the selected red-orange standard.

Table 1 presents the Munsell notations for the colors used. The notations for ordinary red-orange and fluorescent blue represents visual estimates made through the use of the Munsell Book of Colors. The notation for fluorescent blue, especially, should be considered approximate. The notations for the remaining colors were obtained by the spinning disk method and were supplied by the manufacturers of the respective paints.

Table 1

Munsell Notations for the Colors Tested

	Hue	Value	Chroma
Fluorescent Red-Orange	6.0-6.8R	5.8-6.5	20.0-25.0
Fluorescent Yellow-Orange	7.5-8.0R	7.0-8.0	20.0-25.0
Fluorescent Blue	7.25B	5.0	10.0+
Ordinary Red-Orange	7.5R	5.0	12.0+
Ordinary Yellow-Orange	1.0YR	6.0	15.0
Ordinary Blue	2.5PB	4.0	8.0

Apparatus

The perimetric measurements were made on a Brombach Perimeter (American Optical Company). The experimental situation is shown in Figure 2. The measurements were made in a darkened room with the only illumination provided being that from the 60-watt daylight bulb housed on the perimeter itself. Since the lamp rotates with the arc, constant illumination on the stimuli (measured with a G. E. photographic light-meter to be approximately 12.5 foot-candles) was maintained for all positions of the arc.

Figure 2 Experimental procedure

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Subjects

Measurements were made on nine subjects, all males, ranging in age from 18 to 27 years. All had normal color vision as determined through the use of a standard series of pseudo-isochromatic charts.

Procedure

The stimuli in all cases were the same size (6.5 mm. in diameter) and subtended approximately 1° of visual angle when situated at the normal perimetric measurement distance. For a given subject measurements were made using first either all three fluorescent or all three ordinary colors. With alternate subjects, the order of presentation was reversed to counterbalance fatigue or other sequence effects. Measurements for a white test stimulus were made with both series.

The white test object was used with each group of stimuli as an added control to determine whether sequence effects were actually present. This procedure in which the three fluorescent stimuli plus the white stimulus comprised one series and the three ordinary colors and white comprised the other, was considered best due to the inadvisability of presenting the several blues, oranges, or reds in a single series of measurements. Other arrangements could, of course, be suggested, but all would leave something to be desired in the way of control.

Finally, within each series, the order of presentation of the colors was randomized so as to control as much as possible for errors of anticipation.

For each subject, each of the seven test objects (eight, if white is counted twice) was brought in from the periphery at each of the eight basic meridians (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°) a total of five times. Thus, an average score based on five measurements was obtained at each meridian for each stimulus. For the red-orange and blue fluorescents and their respective ordinary color counterparts, two points on each meridian were measured: (1) that point at which the stimulus was first seen, usually as a white or gray object (henceforth called the "Outside Limits" measurement), and (2) that point at which the true color of the test object could be identified (henceforth called the "Inside Limits" measurement). For the yellow-orange fluorescent

and its ordinary color counterpart and for white, only the first of these measurements was made. Determination of the Inside Limits zones was not made for the yellow-orange stimuli because of the difficulty experienced by subjects in distinguishing between these and the red-orange stimuli and the consequent confounding which would have occurred had the "true color" measurements for both sets of stimuli been obtained. The subjects' confusion is understandable in light of the fact that any color will often first take on a yellowish tint as it is moved in from the periphery. Thus, a red-orange stimulus placed farther out in the periphery can easily be confused with a yellow-orange stimulus at a point several inches closer to the central fixation point.

Each subject was adapted to the test illumination level prior to testing, and at least one practice trial with each color of the first series was then given to acquaint the subject with the stimuli and the procedure to be used. At prescribed intervals in the testing, rest pauses were given to minimize visual fatigue. Measurement in all cases was for the right eye only; the left eye was covered with an eye patch. After the measurements were obtained for each subject, the zones generated were graphed and checked for "normalcy." The question here was simply whether the general shapes of the fields approximated those normally found in perimetric work; size of the fields was not considered. As a result of this review, the data of one subject were eliminated because of the extreme distortion in the shape of his Inside Limits fields*.

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* Extensive eye movements, if they occurred for this subject, went unnoticed by the tester, who checked for eye movements during the testing. Since only the Inside Limits zones were distorted, and not those for the Outside Limits, it is possible that the subject simply had unusual difficulty maintaining a frame of reference with respect to the "true" color in each case. To be on the safe side, however, none of the data obtained on this subject were used.

III. RESULTS AND DISCUSSION

Two sets of measurements were obtained with each stimulus for each subject. The first, referred to as the Outside Limits measurements, comprised that point on each meridian at which the stimulus was first seen, usually as a white or gray object. This set of measurements was made for all test stimuli.

The second set of measurements (Inside Limits), made only for the fluorescent red-orange and fluorescent blue stimuli and their ordinary paint counterparts, comprised the point on each meridian at which the true color of the test object was perceived.

In terms of the in-flight situation, it may be argued that the Outside Limits measurements possess greater practical significance than the Inside Limits measurements. An exterior paint color which alerts the pilot more quickly than a second color to the fact that an intruding aircraft is approaching can be judged to be superior. Although the Outside Limits measurements do not represent the "true color" zones for the colors tested, they do reflect the limits at which the respective colors are effective as stimuli per se. It may be expected that once a pilot becomes "aware" of an intruder, he will focus foveally on the intruding aircraft. Thus, from the perimetric point of view, the Inside Limits measurements are considered to possess less significance than the Outside Limits measurements.

Inside Limits

Figure 3 presents the average Inside Limits data. Relative sizes of the fields may be easily distinguished from the largest to smallest: (1) fluorescent blue, (2) ordinary blue, (3) fluorescent red-orange, and (4) ordinary red-orange. These data are in accord with what has been found by previous investigators with respect to the relative size of the fields for blue and red (Boring, 1942). In addition, the data are in accord with what would be expected if we assume greater energy from the fluorescent stimuli (both fluorescent paints yielding larger visual fields than their ordinary color counterparts).

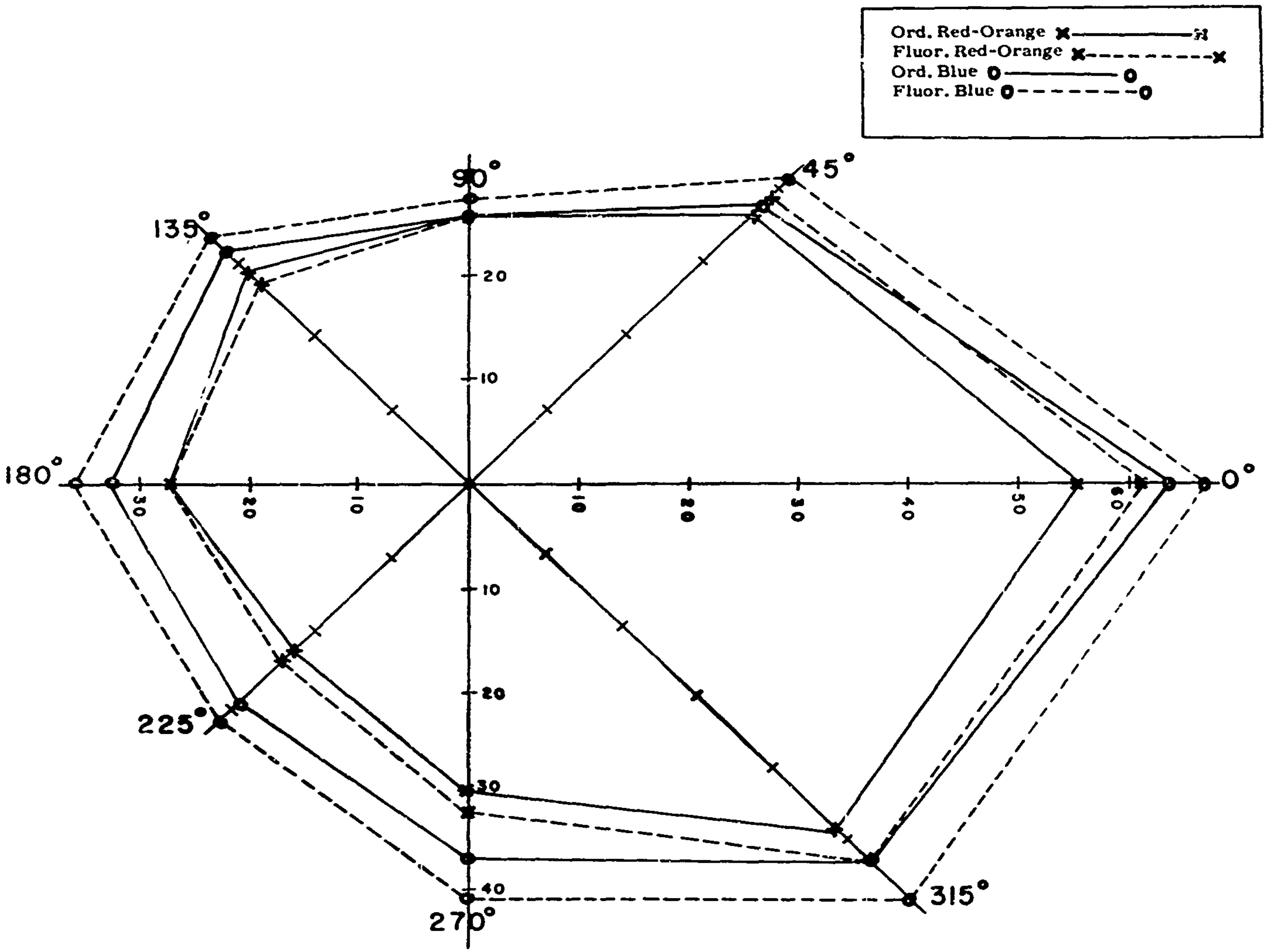

FIGURE 3 AVERAGE VISUAL FIELDS (INSIDE LIMITS MEASUREMENTS) FOR FOUR COLORS

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In order to obtain some estimate of the statistical significance associated with differences between fields, Wilcoxon's matched-pairs signed-ranks test was applied. A member of a matched pair in this case was the average limit (across subjects) in degrees, at a given meridian for a given color; the other member of the pair was the corresponding score for a second color. Thus, eight pairs of scores corresponding to the eight average meridional measurements obtained for the two colors evaluated were included in each comparison. Table 2 presents the average (across meridians) differences, in degrees, between pairs of colors and the levels of significance (signed-ranks test, two tailed) associated with the differences among the colors.

Consideration of the average degree differences among the fields yields the same rank order of relative size as obtained by visual inspection. However, not all of the differences between the fields were statistically significant. The differences between the fields for fluorescent red-orange and ordinary red-orange and for fluorescent red-orange and ordinary blue, although approaching significance, were not sufficiently great to allow for confident rejection of the null hypothesis.

Outside Limits

The average Outside Limits data for the eight subjects are presented in Figure 4. It is clearly apparent from Figure 4 that the fluorescent stimuli as a whole yielded larger average fields than did their ordinary color counterparts. Application of the signed-ranks test confirms what is apparent visually. Using as one member of a matched pair the average (across subjects) zonal limit at each meridian for each of the three fluorescent stimuli, and as the other member of each pair the corresponding zonal limit obtained for each of the ordinary color stimuli, the obtained difference between the fields associated with the fluorescent and non-fluorescent stimuli is statistically significant at the .01 level of confidence (two-tailed test). The average difference between these composite fields was 2.0 degrees.

Statistical tests were also performed on each pair of colors separately, as in the case of the Inside Limits data. Table 3 presents the results of these tests and the average differences between pairs of colors. Disregarding the white stimulus, it is seen that in no case did an ordinary color yield a larger average field than a fluorescent stimulus, although not all differences between fluorescent and ordinary paint colors are significant. It should be noted, however, that those differences which are statistically significant are between a fluorescent and a non-fluorescent stimulus; no significant differences are present within either group considered separately.

TABLE 2

AVERAGE DIFFERENCES, IN DEGREES, AMONG FIELDS AND LEVELS OF SIGNIFICANCE ASSOCIATED WITH DIFFERENCES AMONG FIELDS (INSIDE LIMITS MEASUREMENTS)

AVERAGE DIFFERENCES[a]

	RED ORANGE (ORD.)	RED ORANGE (FLUOR.)	BLUE (ORD.)	BLUE (FLUOR.)
RED-OR. (ORD.)				
RED-OR. (FLUOR.)	> 1.8			
BLUE (ORD.)	> 4.4	> 2.6		
BLUE (FLUOR.)	> 7.1	> 5.3	> 2.7	

LEVELS OF SIGNIFICANCE

	RED ORANGE (ORD.)	RED ORANGE (FLUOR.)	BLUE (ORD.)	BLUE (FLUOR.)
RED-OR. (ORD.)				
RED-OR. (FLUOR.)	.10–.05			
BLUE (ORD.)	.02	.10–.05		
BLUE (FLUOR.)	.01	.01	.01	

a THE INEQUALITY SIGN (>) INDICATES THE LARGER FIELD IN EACH CASE WHEN THE TABLE IS READ IN A ROW-COLUMN SEQUENCE.

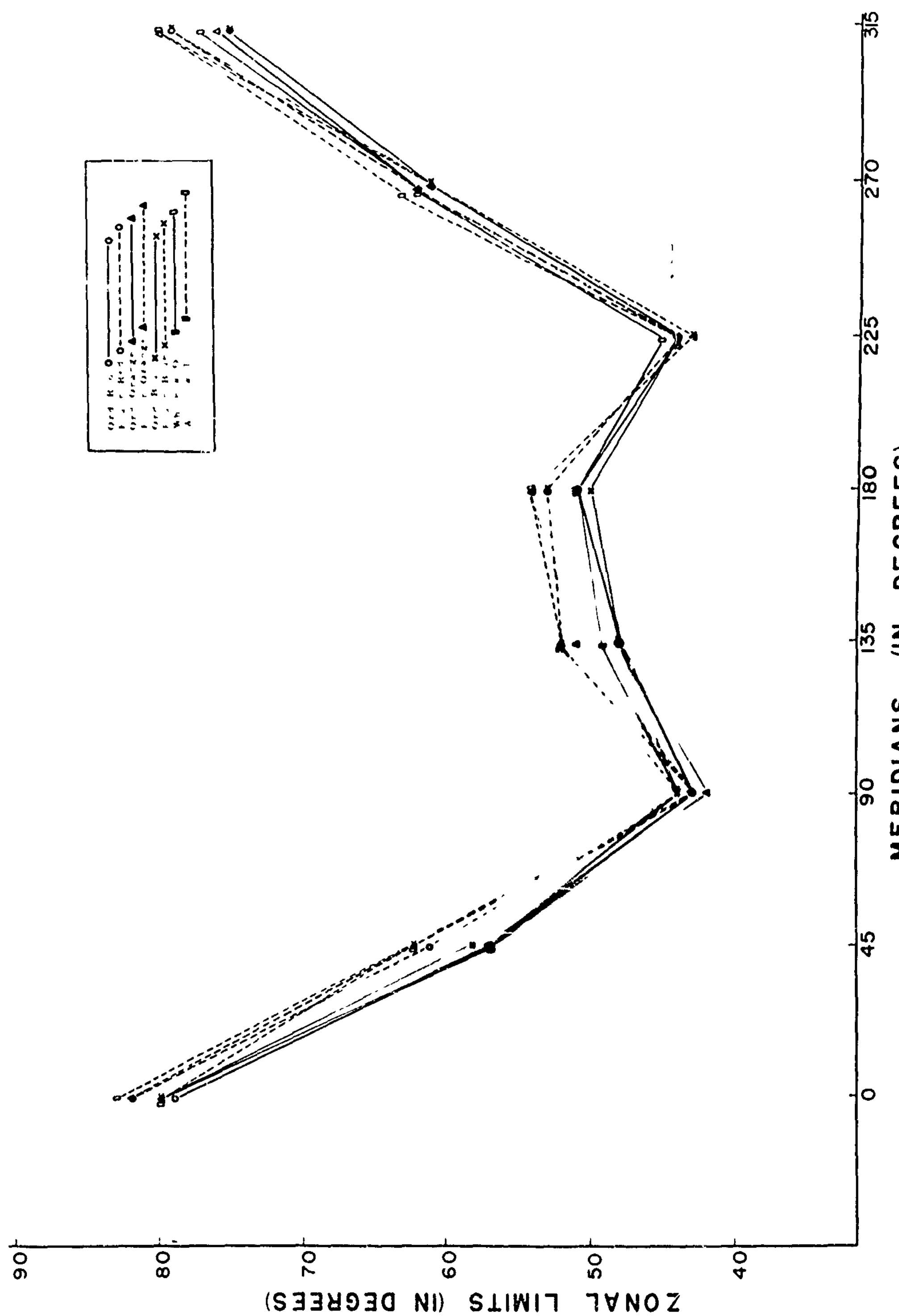

FIGURE 4 AVERAGE VISUAL FIELDS (OUTSIDE LIMITS MEASUREMENTS) FOR SEVEN COLORS

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TABLE 3

AVERAGE DIFFERENCES AMONG FIELDS AND LEVELS OF SIGNIFICANCE ASSOCIATED WITH DIFFERENCES AMONG FIELDS (OUTSIDE LIMITS MEASUREMENTS)

AVERAGE DIFFERENCES*

	RED ORANGE (ORD.)	RED ORANGE (FLUOR.)	YELLOW ORANGE (ORD.)	YELLOW ORANGE (FLUOR.)	BLUE (ORD.)	BLUE (FLUOR.)	WHITE (ORD.)	WHITE (FLUOR.)
RED—OR. (ORD.)								
RED—OR. (FLUOR.)	> 2.2							
YELL.—OR. (ORD.)	< 0.2	< 2.0						
YELL.—OR. (FLUOR.)	> 2.2	0.0	> 2.0					
BLUE (ORD.)	> 0.2	< 2.0	0.0	< 2.0				
BLUE (FLUOR.)	> 2.0	< 0.3	> 1.8	< 0.2	> 1.8			
WHITE (ORD.)	> 0.8	< 1.4	> 0.6	< 1.4	> 0.6	< 1.2		
WHITE (FLUOR.)	> 3.0	> 0.8	> 2.8	> 0.8	> 2.8	> 1.0	> 2.2	

LEVELS OF SIGNIFICANCE

	RED ORANGE (ORD.)	RED ORANGE (FLUOR.)	YELLOW ORANGE (ORD.)	YELLOW ORANGE (FLUOR.)	BLUE (ORD.)	BLUE (FLUOR.)	WHITE (ORD.)	WHI (FLU
RED—OR. (ORD.)								
RED—OR. (FLUOR.)	.05							
YELL.—OR. (ORD.)	—	.05						
YELL.—OR. (FLUOR.)	.10—.05	—	.05					
BLUE (ORD.)	—	.05—.02	—	.10				
BLUE (FLUOR.)	.05	—	.10	—	.20—.10			
WHITE (ORD.)	.05	.10	.20	—	.20	—		
WHITE (FLUOR.)	.02	.05	.02	.10	.05	.10	.05—.02	

* THE INEQUALITY SIGN (>) INDICATES THE LARGER FIELD IN EACH CASE WHEN THE TABLE IS READ IN A ROW—COLUMN SEQUENCE

The White Stimulus

A white stimulus was presented within both the fluorescent paint series and the ordinary paint series. When the white test object was presented with the fluorescent stimuli, it yielded the largest field of all, although the differences between white and fluorescent yellow-orange and white and fluorescent blue were not statistically significant. The same test object presented within the series of ordinary colors yielded a smaller field, significantly different from that obtained with the stimulus in association with the fluorescent colors. Why such a result should be obtained is problematical. The white test object was the same in either case, and it was presented in the same manner in all cases by the same experimenter. The difference could not be the result of fatigue or "practice" since half of the subjects were presented with the fluorescent stimuli first and the other half with the ordinary paint stimuli first*. Neither can the obtained results be attributed to bias on the part of the subjects since all but one of the subjects were naive with respect to the significance of the specific stimuli involved. For the single subject who was not naive with respect to the purposes of the experiment, parenthetically, the white fields generated ran contrary to the trend in that the larger of the two was the field generated in association with the ordinary color series.

While several alternative explanations for the finding for the white stimulus object are possible, the most parsimonious appears to be in terms of an anticipational error associated with the series in which the white stimulus was presented. Thus, it is possible that white when presented within the fluorescent series tended to be anticipated and reported at about the same time as the other paints in

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* Since alternate subjects began each run with either the fluorescent or ordinary stimuli, the white test object was presented within the fluorescent and ordinary paint series an equal number of times in either half-run. It will be remembered that the reason that the white test object was presented with each series of colors in the first place was to check on the presence of a sequence effect. With respect to this latter point, a signed-ranks test of the difference between the white field generated from the data obtained in the first half of each run and that generated from the data of the second half was not significant.

the fluorescent series; when white was presented within the ordinary paint series, it became anticipated and reported at about the same time as the ordinary paints. Whatever the explanation for the effect, however, it should be clear that the results obtained for white are due to the methodology involved and not to manipulated experimental variables.

Such an effect could very well have been exerted over the other Outside Limits measurements reported and could have been instrumental in producing the lack of statistically significant Outside Limits differences noted within each color series.

Because of the random presentation of stimuli within each series, the anticipational effect might be assumed to be equally distributed within each set of data. Whether an anticipational effect was in fact present or whether some other factor produced the differential effect on white is not known. Moreover, the question remains as to whether the effect was equally strong for both sets of data. Because the answers to these questions remain equivocal, the within series Outside Limits measurements must be looked upon as tentative.

This finding further suggests that perimetry measurements could be more sensitive than customarily supposed to anticipational effects (or other series effects) resulting from serial presentation of the stimuli. The effect if confirmed would suggest that such measurements, at least when precise determination of absolute Outside Limits are required, should be made in a manner which will not allow any possible series effect (including "set") to influence the data.

IV. SUMMARY

From the visual perimetric point of view, the more useful aircraft exterior coloration in terms of mid-air collision avoidance is that coloration which affords color zones of the greatest magnitude. The present experiment comparatively evaluated the visual fields of selected fluorescent paints with "matched" ordinary paints. Inside Limits and Outside Limits determinations were made. The Inside Limits measurement represents the point on a meridian at which a colored stimulus object, when brought slowly inward, is first recognized in its true color. The Outside Limits measurement represents the point on a meridian at which the stimulus object is first seen, usually as a gray stimulus. The results suggest that, from the perimetric point of view, the fluorescent paint colors employed possess greater fields than the ordinary color samples used in the present experiment. By extrapolation, support may be given to a general contention favoring the use of fluorescent paint for purposes of aircraft detectability and visibility.

For the color samples employed:

1. although all possible comparisons did not yield statistically significant differences, the Outside Limits zones for the fluorescent paints were in all cases greater than the corresponding Outside Limits zones for the ordinary colors

2. similarly, the Inside Limits measurements for the fluorescent paints were greater than the Inside Limits for the "matched" ordinary paint colors

3. with each paint type, fluorescent and ordinary, the obtained visual fields (Inside Limits) followed those found in previous perimetry work, i.e., larger fields for blue than for red

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